ALL ABOUT PULSE GENERATORS

This month we'll look at another pulse-generator application, testing analog circuits, as well as some problems that you might run into when you use that device.

CHARLES GILMORE

Part 4 SO FAR WE HAVE CONfined our discussion to using the pulse generator in logic-circuit analysis. While that is one of the prime functions of the pulse generator, it is not its only one. Let's begin this month by looking at another area where the pulse generator is useful—testing and analyzing analog circuitry.

Analog circuits

Using a pulse generator as a signal source can simplify many of the measurements that are often made when testing analog circuits. That's because, generally speaking, pulse generators are useful over a very wide frequency range, which can come in handy when working with broadband amplifiers, etc.

For instance, a single, conventional, pulse generator is the only signal source you need to test an amplifier whose frequency response extends from below 1 Hz to considerably more than 10 MHz. Otherwise, testing that amplifier would require using an audio generator for the low end and an RF generator for the upper end, or perhaps a very wide-range function generator.

The reason for that becomes apparent if the nature of a pulse is analyzed. Such analysis would reveal that the pulse's fast rise and fall times are caused by the pulse's high-frequency components, while the interval between the rise and fall times (i.e. the top of the pulse) is caused by the low-frequency components; in some cases, the frequency of those components is so low that it is approaching DC. Those high- and low-frequency components are what gives the pulse generator its wide frequency range.

Frequency-response measurements on an amplifier are usually made at the 3-dB points; that is, the point at which amplifier delivers half its rated power output, or 70 percent of its rated voltage output. That 3-dB point is considered the upper and lower cutoff frequency of an amplifier. The simplest method to measure the low-frequency 3-dB cutoff is by adjusting the pulse generator so that the pulse *droop* is 25 percent. Pulse droop (the difference between the amplitude immediately following the leading edge and the amplitude at which the trailing edge begins) is expressed as a percentage of the amplitude at the leading edge (see Fig. 11).

When the pulse droop is adjusted to 25 percent, the width of the pulse is related to the frequency (in Hz) of the lower 3-dB point through the formula:

$$f_{low} \approx \frac{0.0456}{t}$$

where t is the width of the pulse. The constant (0.0456) is derived from a Fourier analysis of the pulse.

To measure the frequency of the upper 3-dB cutoff, the following formula is used:

$$f_{upper} = \frac{0.35}{t_r}$$

where f_{upper} is the upper 3-dB cutoff frequency (MHz), and t_r is the pulse risetime in nanoseconds.

While that formula has been idealized and is for a circuit where the product of the capacitance and inductance is 0, the formula will hold until that product exceeds 0.25. After that point, some overshoot begins to occur at the end of the leading edge, lowering the value of the constant, 0.35, in the formula. With overshoot of 25 percent, for instance, that constant would be lowered to 0.28.

Some additional information about the frequency response of a broadband amplifier can be obtained using a pulse generator. Remember that a pulse con-

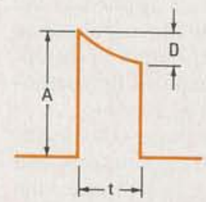


FIG. 11—PULSE DROOP is useful in finding the lower 3-dB point of an amplifier.

sists of a fundamental frequency plus a great number of even and odd harmonic components with specific phase relationships with each other, as well as with the fundamental frequency. If that phase relationship is not maintained, the waveshape of the pulse deteriorates. If an essentially stable pulse waveform is passed through an amplifier, the amplifier's output can be examined for any aberrations in that waveform. The presence of those aberrations indicates that the phase response of the amplifer is not uniform—i.e., that there are peaks and/or valleys in the amplifier's frequency-response curve. That would be caused by either leading or lagging reactive elements in the circuit. At that point, further analysis with a sweep generator or a low-distortion audio oscillscope is needed.

As noted earlier, rise-time measurements let you determine approximately the upper frequency-response limits of a broadband amplifier. A few precautions must be taken when making such rise-time measurements. One thing that must be considered is the effect of the test setup. Each part of that setup plays a role in determining the rise time of the output that is displayed; in other words, the rise time of the pulse is changed slightly as it passes through the various parts of the test setup. The displayed rise time, therefore, is actually a function of the rise times through each part of that setup and can be found from:

$$T_R = 1.1 \sqrt{T_G^2 + T_A^2 + T_P^2 + T_O^2}$$

where T_R is the display rise time, T_G is the rise time of the pulse generator, T_A is the rise time of the amplifier under test, T_P is the rise time of the probe, and T_O is the rise time of the oscilloscope.

Because of its exceedingly fast rise time, a pulse generator is extremely convenient for measuring propagation delay and phase delay. Both analog and digital circuits introduce some fixed time delay to signals that pass through them. For example, if a J-K flip-flop is clocked, it will take several nanoseconds for the results of that clocking to appear at the output of the flip-flop. That delay in response is called the propagation delay of the flip-flop.

Analog amplifiers also suffer from propagation delay. The easiest way to measure that delay is to use a dual-trace oscilloscope and a pulse generator. The pulse-generator output is applied to the amplifier's input and to one oscilloscope channel. The amplifier output is the applied to the second channel of the oscilloscope, and a comparison is made.

If a dual-trace oscilloscope is not available, you can use a pulse generator with a pulse-delay capability. In that case, the input to the amplifier is connected to the delayed generator output. The amplifier output and the non-delayed pulse-generator output are both applied to the oscilloscope. The pulse-delay control of the generator is then adjusted until a single pulse is obtained. The amount of delay neccessary to display the single pulse is equal to the propagation delay of the amplifier.

In order to successfully combine the amplifier output with the pulse-generator output, some series-limiting resistance must be used. Great care must be taken to insure that the added circuitry does not contribute additional phase shift. Figure 12 shows an example of such a situation.

Pulse generators are also useful in evaluating the high-frequency charateristics of diodes and transistors. The diodes used in either radio-frequency or digital applications are required to recover very rapidly from switches between reverse- and forward-bias.

When a diode is forward-biased, the area at the junction is filled with majority carriers. ("Majority carrier" is a term used in semiconductor electronics to describe the predominant type of carrier in a semiconductor material. In n-type material, the predominant carrier is the electron; in p-type material it is the absence of an electron, which is called a *hole*.) When the diode is reverse-biased, the junction has few majority carriers. Obviously, the change in the number of majority carriers at the junction can not occur instantaneously.

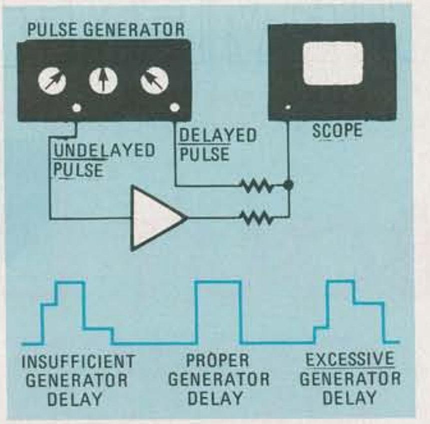


FIG. 12—A PULSE GENERATOR is used here to measure the propagation delay through an amplifier.

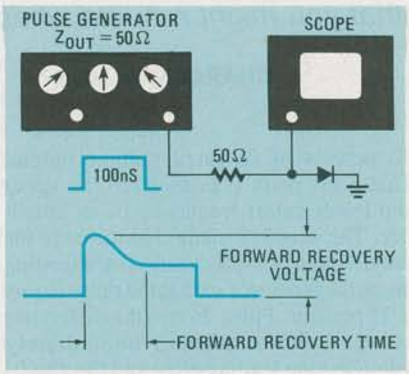


FIG. 13—MEASURING THE FORWARD recovery voltage and forward recovery time of a switching diode. The pulse generator should be set for a 100-nanosecond pulse width with a less than 1 percent duty cycle. The output voltage of the generator should be set to produce a specified steady-state current in the diode.

Let's first look at what happens when a diode is suddenly switched from reverse- to forward-bias. When that happens, the majority carriers move to the area around the junction. But, until that area is filled with those majority carriers, the voltage across the diode is considerably greater than its normal forward-biased voltage. That voltage *transient* is of concern if the diode is to be used in switching applications. Figure 13 shows a test setup that can be used to measure that *transient*, as well as the waveform that would be displayed on the scope. The size and duration of the transient can be found by inspecting the waveform as shown.

The forward-recovery specifications of a diode are normally given for some steady forward-current value, once the transient conditions have subsided. It is that forward current, combined with a 50-ohm resistor, that determines the pulse generator's output voltage; pulse duration should be 100 nanoseconds. A generator having a 10- to 20-nanosecond rise time is suitable for that test, and no offset voltage is required.

Now, let's consider what happens when a diode is suddenly reverse-biased. When that happens, a large reverse current flows until there are few majority carriers left around the junction. How long that current flows is important if a diode is to be used in a switching application. Figure 14 shows the test setup used to measure that, as well as the waveform that is likely to be seen on the scope.

The requirements placed on the pulse generator and the oscilloscope used to measure reverse-recovery time are somewhat greater than those for forward-recovery time. Reverse-recovery time in diodes is on the order of a few nanoseconds, and the rise time of the pulse generator must be considerably less. In many cases, the rise time of both the pulse generator and the scope must be less than 1 nanosecond. However, generators with more moderate specifications can be used to test slower diodes.

Figure 15 shows the test setup used to measure the turn-on and turn-off times of a switching transistor, as well as the typical waveforms that would be displayed on the scope. That test is one of the most important ones done when you are analyzing the operation of a switching transistor.

As with a diode, transistor specifications are given at some specified base- and collector-current levels. The bias and B+ voltages supplied to the circuit establish proper transistor operation and should be selected so that those currents are at the proper level. Note that turn-on time is determined by noting the point where the generator's output rises to 10 percent of its final value and the point where the transistor's output drops to 90 percent of its initial value. Conversely, turn-off time is measured between the points where the generator's output drops 10 percent from its maximum level, and the transistor's output rises to 90 percent of its initial value. Once again, for transistors with reasonable switching speeds, the pulse generator and the oscilloscope must have relatively good rise-time specifications. However, pulse generators with more moderate capabilities can be used to perform those tests on some slower transistors. Other transistor measurements that can be made include storage time, stage rise time, and voltage breakdowns.

Using a pulse generator when testing transistors and diodes has several advantages. Two of the most obvious are that they can be used to supply a bias offset voltage, (eliminating additional power supplies) and that their sharp rise times eliminate the need to measure the rise time of the generator itself. In addition, pulse generators can be operated at extremely low duty cycles. For instance, in the diode and transistor tests we just discussed, duty cycles of one percent or less are called for. Such low duty cycles let you perform tests that could not be safely done under steady-state conditions. Such steady-state testing would overheat many of the devices, possibly destroying them, or at least changing their electronic characteristics. Even though peak power developed in a circuit when using a pulse generator may far exceed the maximum permissible continuous power, with that device's low duty-cycle the average power is well within its ratings.

Sources of error

A pulse generator is probably one of the easiest instruments to use improperly. The vast number of settings and modes make it easy to set up improperly. Therefore, using a pulse generator without an oscilloscope is not advisable. With a scope, you can easily spot setup errors and correct them.

The most frequent errors in using a pulse generator are human errors. For example, a common mistake is exceeding the allowable duty cycle. As noted earlier, a 70 percent duty cycle is common for most pulse generators. The most usual mistake here, however, does not involve exceeding the duty cycle by a small amount (such as 75 percent as opposed to 70 percent, for example), but by exceeding it by orders of magnitude. That happens when, for instance, a pulse-repetition rate of 1 kHz has been established, but a pulse width of 10 milliseconds is chosen instead of 10 microseconds. In that situation, the duty cycle has been exceeded by a factor of 10.

On pulse generators with a pulse-delay feature, a similar error occurs. In that case, the delay time exceeds the time established by the pulse-repetition rate. A pulse generator set for a repetition rate of 1 pulse-per-millisecond might have the delay generator set at 10 milliseconds. Due to the nature of the monostable multivibrator used to generate the delay time, the first pulse is chosen to generate the 10-millisecond delay interval, and the following nine pulses are ignored. The result is one pulse-per-10 milliseconds, even though the pulse-repetition rate has been set for 1 pulse-per-millisecond.

Variable rise- and fall-times, although a useful feature, can also give rise to errors. For instance, assume a pulse width of 20 nanoseconds is desired. If, however, the rise- and fall-times are set at 15 nanoseconds, the time required to reach the maximum output and drop back to zero would be a total of 30 nanoseconds, 10 nanoseconds greater than the pulse width. Thus, the pulse does not have enough time to reach the proper levels, making any measures of amplitude incorrect.

As noted previously, improper transmission lines or terminations can seriously degrade pulse characteristics. Care must be taken to prevent pulses that are distorted beyond recognition.

In similar fashion, certain situations require the pulse to be split between two different transmission lines and later recombined by some form of circuity. If narrow pulses at a high rate, and relatively long cables are used, great care must to taken to insure that both pulses arrive at the proper termination simultaneously. If that is not done, pulse-stretching may occur.

In many cases, both the amplitude and the offset controls of the pulse generator have extremely coarse calibration; that can cause misadjustment. Errors can easily occur when setting the generator's output amplitude. A 50 percent setting, for instance, does not mean 50 percent of the rated amplitude. The output specification of the generator indicates a maximum output, but that output is usually given in terms of "not less than." In many cases, the actual output can exceed that rated output by as much as 20 to 25 percent. As a result, the most accurate way to set the output amplitude is to monitor the generator's output on a scope. Another possible error in setting the output amplitude can be introduced by using an output attenuator. Those errors are caused by using the wrong level of attenuation and are quite large—at least one order of magnitude.

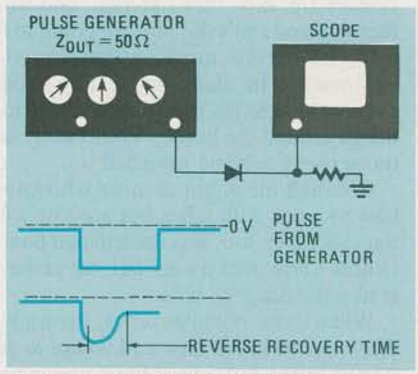


FIG. 14—MEASURING DIODE reverse-recovery time. A 100-nanosecond pulse-width with a duty cycle of less than 1 percent should be used. The generator rise time should be less than the expected reverse-recovery time. The positive pulse offset is set to generate the specified forward current. A 60-ohm resistor converts the output current to voltage for display on the oscilloscope.

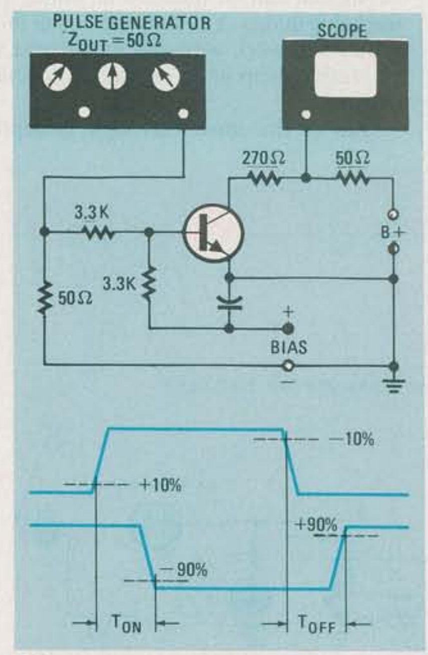


FIG. 15—MEASURING THE SWITCHING time of a transistor. The pulse generator is set for a 100-nanosecond pulse-width with a duty cycle of less than one percent.

Generator-induced errors

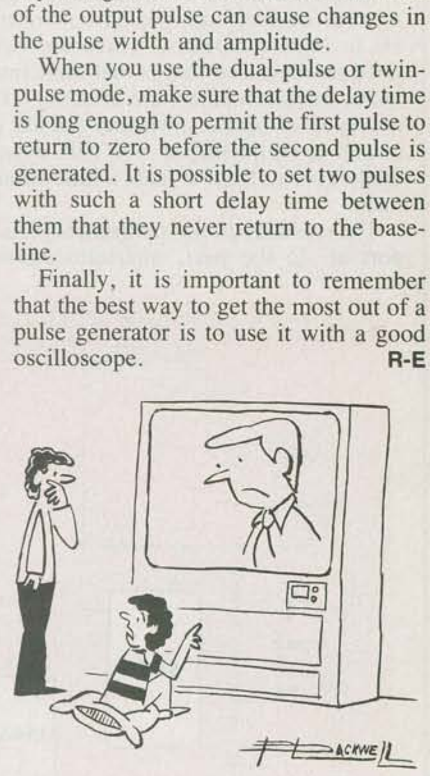
A pulse generator is usually not calibrated very precisely. However, if you are fully aware of all its specifications and what they mean, you will have little or no problem in getting maximum use from the instrument. However, failure to recognize some of these specifications can result in generator-induced measurement errors. Jitter can occur in the repetition rate, the amount of pulse delay, and the pulse width. The amount of jitter must be taken into consideration when a rather stable pulse-width, delay, or repetition-rate is required.

When using a pulse generator, especially over extended periods of time, it is necessary to reset the operating parameters, many of which can vary over time, or with changes in temperature and other factors. Certain pulse-generator characteristics are affected by changes in the load (for example, the baseline offset, which is often simply a current generator operating into a known load).

Frequently, certain pulse-generator controls interact somewhat. For example, any changes in the rise time and fall time of the output pulse can cause changes in the pulse width and amplitude.

When you use the dual-pulse or twin-pulse mode, make sure that the delay time is long enough to permit the first pulse to return to zero before the second pulse is generated. It is possible to set two pulses with such a short delay time between them that they never return to the baseline.

Finally, it is important to remember that the best way to get the most out of a pulse generator is to use it with a good oscilloscope. **R-E**



"I'd like to turn it off, father, but he's telling me to stay tuned, and he's *bigger than you!"*